Shape memory actuated sliding mechanism for rapid switching between button-patterns for adapted human-machine interaction at different automatization levels in automobiles

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Abstract. Almost all electronics and mechanical equipment have controllers to control the entire or certain tasks. These controllers respond to various types of inputs and performs the function accordingly. One type of input given to the controller is the touch and these controllers which use human touch has touch screen to act as the medium. The touch screen does not give haptic feedback to the users whereas the buttons normally take up more space and cause disturbance and confusion in recognizing the state and the function of the buttons. In this paper, we propose a simple sliding mechanism for rapid switching between different button patterns, in which the buttons remain flat in the surface when inactive and protrude out of the surface when active. The design and simulation are carried out on SolidWorks and the prototypes are fabricated and tested. This mechanism incorporated in the buttons and installed in an automobile, increases the level of automation and enhances the human-machine interaction.

1 Introduction

Nowadays automobiles are used vastly in various applications from personal to commercial and the automobiles have evolved from manual to semi or fully automated and one of the most important components that aided the evolution is the controller. The controllers which are used in automobiles are used to perform several functions ranging between turning-on to self-driving and also controllers could be either handy and portable or also fixed to the automobile. The controllers are used in automobiles to control almost all of its components and it could be that one controller to control all the functions in an automobile or a controller to control a specific function or a specific component in an automobile. Most of the controllers which are used in automobiles receives signal by human touch, and they could be in the form of touch screen or having buttons. The controllers with the buttons are bulky and also have several disadvantages like ambiguity in recognizing the functions of the buttons and also in differentiating between the active and inactive buttons. The advanced and latest controllers are touch screen where the humans can touch and interact

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with the screen to perform the functions, but this kind of interaction does not provide haptic feedback to the user which is necessary for effective communication between the human and the machine and will also adapt the design according to the necessities of the user and improve the safety of the automobile. [1]

A reconfigurable, shape-changing buttons on a vehicle control panel could be made to use shape memory alloy and/or shape memory polymer to control the movement of the buttons during active and inactive states. [2] During the inactive state, the button remains on the surface and when it is changed to the active state, there is a protrusion and this protrusion is in a hemispherical or dome shaped.[2] There is a compliant mechanism which includes single-piece flexible structure which can deform in three dimensions and transmit force to an input actuation. In another method, a mechanism could be developed to provide concealable physical buttons, while the display associated with the buttons and surroundings remains stationary. [3] In this the buttons or hard keys are concealed to the surface when not interacting and raised above the surface when needed. This motion occurs due to the presence of a motor, a threaded shaft coupled to the motor, a movable platform coupled to the threaded shaft and a hard key movably supported on the movable platform and the due to this arrangement and the movement of the motor, the hard key rises from the surface when required and this also provides haptic feedback to the end-user.[3] In this method, the space required by the setup is quite high and the mechanism is complex and the number of parts used is also large. Due to these, the power required for the actuation would also be high. In another method, the buttons rise above the surface on demand by the help of Tactus Technology. [4] In this, the button is formed with pressure in small channels inside of the substrate and small holes let the fluid in the area in-between the elastomer and the substrate. The rise occurs due to the expansion of the elastomer surface when the compressed fluid is allowed to pass through the small channels. [4] The compressed air and the micro-valves are switched using energy. This method is most suitable for touch screens. By, this method, the transparent buttons are possible. In this technology, the response time might be slow and liquid leakage could be a potential problem.

The buttons on demand are necessary as it increases the human-machine interaction and also not all the buttons are required during operation of vehicles, for example, there is no need of automatic parking buttons when the automobile is in highway at a great speed and if the automatic parking button is activated accidentally, it might induce certain problems and dissatisfaction to the users. SAE levels of a vehicle are classified based on the engagement and the performance of the features of the vehicle by the driving system. At SAE level 0 – 2, human drivers are responsible to monitor the driver environment, whereas for vehicles at SAE level 3 – 5, the automated driving system monitors the driving environment. [5, 6] For changing the different levels of automation at different points of time, an adaptation of the human machine interaction concept is necessary.

This paper presents a novel approach for the buttons on demand, in which the buttons remain concealed in the surface when the buttons are inactive and the buttons come out of the surface when they are in active. In this way, the space occupied and the ambiguity in recognizing is reduced as well as the haptic feedback is given to the user and also the mechanism used for the rapid switching between the active and inactive states of the controller is explained in details. This is achieved by sliding mechanism which could be actuated by means of such as electric switches and shape memory alloy (SMA), such as Ni-Ti alloy spring. The mechanism was designed and simulated using SolidWorks and then the prototypes were fabricated by CNC machining and laser cutting. The performance of the device was tested.

2 Design of controller with sliding mechanism for rapid switching

The controller that is designed has a linear series of seven buttons in which there are four buttons which possess the function of rapid switching of button pattern, while the other three buttons are active all the time due to its function and its necessity in the automobile. The controller was designed for the four buttons to rise or fall and possess active or inactive states, while the other three buttons are always concealed to the surface but they are active all the time. The other four buttons are designed such that they possess two positions, in which one has all the four buttons to be inactive and concealed to the surface, while in the other position, the four buttons to be active and risen above the surface. This creates two different surface patterns with respect to the state of the buttons, one pattern has all seven buttons to be concealed to the surface while the other pattern has four buttons that are alternate to the three buttons in a linear manner risen above the surface. There are seven components in the controller that play a major role in the activation process, which are top cover, bottom cover, slider, buttons, mechanochromic material, SMA (wire or spring) and a power source to activate the SMA, such as a 9 V battery. Since, there are two surface patterns obtained by the two positions of the buttons, both two-way SMA or one-way SMA could be used. In this design, we used a one-way SMA and two push buttons to activate the two different positions of the buttons and the respective surface patterns could be obtained. The design was carried out in such a way that the entire controller fits in the hand of humans and the total thickness was limited to 35 mm in which 28 mm goes inside the automobile and only 7 mm is visible and the rise of the buttons from the surface is 1.5 mm. The model of the controller using buttons on demand is shown in Figure 1.

Fig. 1. Model of the controller.

2.1 Top cover

This component acts as a cover for the buttons and the slider, so the working mechanism is not visible. It has four holes which allow four buttons to fit and these four buttons are placed, so that it is alternate with the other three buttons which are active all the time and are on the surface and will never rise or fall. The top cover should be flat, such that when the buttons are inactive and concealed to the surface, the controller looks as if it has no buttons. The top cover should have a provision for bolt or screws such that the top cover

could be fixed to the bottom cover, such that all the rest of the components could be in-between the top and the bottom cover. The inner surface of the top cover should possess certain slots, such that the buttons do not rotate about its axis during the sliding mechanism and this slot further facilitates rise and fall of the buttons. The slot, which assists the rise and fall of the buttons, could be made either separately for each buttons or could be made common, such that interchangeability of buttons is facilitated. All the four edges are extended to the bottom surface, so that it provides a slot for the slider to slide with the minimal friction. A protrusion is provided on the back of the slider for pushing back and forth manually or by any other means. The top cover has a thickness of 3 mm and has an extension in each sides which increases the thickness to 5 mm. Due to the difficulty in fabricating the design using CNC machining process, a simple design was used for fabrication. The fabrication was carried out with aluminium alloy and the surface was oxidized. The top and rear view of the design of top cover in both the simple and actual design of the controller is shown in Figure 2.

Fig. 2. Actual and simplified design of top cover of the controller.

2.2 Bottom cover

The function of this component is to cover the controller and to act as a base and also this is the component which fits to the carrier in the controller, so that all the actuating components are inside the carrier. The most important function of this component is to aid the slider to slide and help in the rise and fall of the buttons. This acts as a base for sliding the slider and the material of the bottom cover was selected to ensure that the friction between the slider and the bottom cover is minimum. The bottom cover has the provision for attaching to the top cover at the edges or corners by having holes to enable bolts, so that it could be tightened with nuts or by any other screws. The bottom cover or the rear cover was fabricated with polymethyl methacrylate (PMMA) by laser cutting. The bottom cover also has a slot for allowing the protrusion on the back of the slider to slide through it and this could be used for attaching a SMA spring or wire. The design and the image of the PMMA bottom cover are shown in Figure 3.

Fig. 3. Bottom cover. (a) Profile design; (b) prototype made of PMMA.

2.3 Buttons

The controller has seven buttons in which three are always active but on the surface while the other four are the buttons that possess the function of buttons on demand and they are placed alternatively to those three buttons. The design of the button was made such that the top surface is flat while the bottom surface has some protrusion to enable the sliding motion of the slider and undergoes rise and fall according to the design. The design was carried out for two patterns with four alternate buttons above the surface in the first pattern and all the seven buttons are on the surface in the second pattern. To improve the visual and touch feedback protrusions based on the functions of the buttons could be made on the respective buttons. The front, rear and isometric view of the profile design of the buttons are shown in the Figure 4.

Fig. 4. Profile design of the Buttons. (a) Front view; (b) rear view; (c) isometric view.

2.4 Slider

The slider and the buttons are the two parts that play the most important role in this mechanism. The slider is a movable part which could in-turn help in the activation and

inactivation of the buttons based on the patterns. The mechanism is designed in such a way that there are two different positions to which the slider could be moved and each position produces a different pattern of buttons on the surface. The slider was designed as a flat plate that has a protrusion along the vertical axis and the design of this protrusion determines the rise and fall of a button which in-turn gives rise to a pattern on the surface of the controller. The slider is attached with a small protrusion in the middle of its bottom surface which helps to maintain its direction and the orientation while sliding. This protrusion slides through a slot, which is cut in bottom cover and this also helps in holding the SMA spring and it is this component which indicates the position of a button (either OFF or ON). The slider was fabricated by CNC machining of aluminium alloy (Al 6061) and oxidizing its surface and is allowed to slide over the bottom cover made of PMMA. The design of the prototype of the slider is shown in Figure 5.

Fig. 5. Design of slider. (a) front view; (b) rear view.

2.5 Mechanochromic material

The top surface of the controller may be enclosed with a thin surface of material called mechanochromic material. Mechanochromic material is a material that changes its colour of emission when the required amount of external mechanical force stimulus like stress or pressure is applied to it. [7, 8] When the buttons rise from the surface, the thin mechanochromic layer is stretched and this creates a localized colour change in the material which shows the difference between the active and inactive buttons in the controller. Thus, the buttons that are above the surface can be seen clearly and separately from the buttons that are concealed to the surface and are inactive. This gives additional visual feedback to the user and improves the human-machine interaction.

2.6 Shape memory alloy (SMA)

Shape memory materials (SMM) are the materials that have the ability to recover their original shapes from a deformed shape by application of certain stimulus, such as heat, light, chemical, electricity, etc. [9] The underlying effect is called the shape memory effect (SME). One of the most important and most widely used SMMs is shape memory alloy (SMA) due to its high performance and ease in development. One of the major forms of SMA is spring. This consumes less power for activation and also requires less space. SMA wire is another configuration which is more advantageous than SMA spring but still in development stages right now. The SMA spring is used in this controller to actuate the

mechanism by its linear contraction and expansion. The SMA spring (NiTi) used here has a one-way SME and it was activated by an electrical power source (9 V battery) for Joule heating in order to bring the SME. The connection is made such that one terminal of the battery is connected to the middle of the SMA spring, while the other terminal is connected to the two ends of the SMA spring and by this connection the spring is made to act like two SMA springs by activating the two ends alternatively. The picture of the SMA spring connection is shown in Figure 6. The wires from the SMA spring are connected to the normally open push buttons which are connected to the battery and activating one push button, the corresponding movement of the SMA spring is obtained. The thermal behaviour of the SMA actuator is determined by the electrical heating power and the cooling mechanisms of the heat conduction and heat convection in the component. Since, the temperature range is below 200°C, heat radiation does not play a significant and need not be considered during design. [10]

Fig. 6. Picture of SMA spring with wiring.

3 Working mechanism

The controller has two push buttons to activate the SMA spring and thus to activate the mechanism for rapid switching. When the push button responsible for making the buttons active is pushed, the current from the battery heats up the SMA spring on one side and since the SMA spring is attached to the slider, it moves the slider to one end, which aids in rising the buttons above the surface and thus resulting in activating the mechanochromic layer and the touch sensitive layer, which could be placed on the top surface. When the other push buttons are pushed, similar activation occurs but the slider is moved to the other end thus making the buttons to fall on the surface. The assembled model of the controller with rapid switching of button pattern mechanism inbuilt is shown in Figure 7.

Fig. 7. Picture of the assembled controller with rapid-switching mechanism inbuilt.

4 Results and discussion

After testing the working of the mechanism in the controller, a thin elastic cloth was used to cover the top surface of the controller to determine the activation and deactivation of the buttons. The working of the controller with the activation and deactivation of the buttons covered by a thin elastic cloth is shown in the Figure 8.

Fig. 8. Working of the controller (top surface covered with elastic cloth) : (a) Inactive state; (b) active state.

The results of the working of controller with an elastic cloth covered on the top shows that there is a considerable amount of stress developed in the cloth and so by replacing the elastic cloth with a mechanochromic material of similar thickness will produce a change in the colour on the top surface around the buttons and thus enhancing the visual interaction between the user and the machine.

In the controllers explained in the Figure 7 and Figure 8, the activation of the battery which actuates the mechanism is done with the help of push buttons or switches. This could be replaced by sensors and the processors so that the sensors (proximity) will sense the human interaction based on the movement of the hands and the processors will help in determining the right action required and the corresponding buttons responsible for that action will be actuated and will become active by providing both visual and touch feedback. Machine learning could be carried out for a particular user so that more enhanced activation of the buttons could be obtained for the specific user.

After testing the working of the mechanism in the assembled model of the controller, the efficiency of the mechanism was determined in-terms of the current required to heat up the SMA spring and the time taken for the SMA spring to activate the mechanism and the number of cycles the mechanism works with a 9 V battery. Then, the surface profile of the buttons on the top surface when they are active and inactive was determined in order to check whether the user has an enhanced visual and touch feedback on the surface, which plays the major role in this controller. The 3D profile data of the top surface of the controller, when the buttons are inactive and when the buttons are active were obtained by using a 3D scanning equipment called Talyscan 150. The surface characterization was

carried out and the data when a typical button was inactive is showed in the form of meshed axonometric diagram in Figure 9. Typical 3D surface topology data of the top surface when the buttons are inactive is shown in the form of Abbott firestone curve and peak count distribution of the surface in the form of particles count histogram in Figure 10. The 2D profile was extracted for the top surface near the centre along the horizontal surface when the buttons are inactive and is shown in Figure 11. To determine the exact rise that was obtained during the working of the controller, 2D profile was extracted near the centre along the horizontal axis when the buttons are active and it is shown in Figure 12.

Fig. 9. Meshed axonometric diagram of the top surface when buttons are inactive.

Fig. 10. Surface topology when inactive. (a) Abbott-firestone curve; (b) histogram.

Fig. 11. 2D profile extracted near the horizontal axis when buttons are inactive.

Fig. 12. 2D profile extracted near the horizontal axis when buttons are active.

4.1 Advantages of using sliding mechanism for rapid switching of button pattern

- It can be actuated manually or by motor(s) whenever required.
- Nine or more button-patterns may be achieved.
- The number of the degree of freedom of the slider is only one or two.
- The actuation and the motion of the slider and the buttons are highly reliable.
- The buttons provide haptic feedback to the users.
- Touch sensing layer may be integrated atop to provide signal feedback.
- A layer of mechanochromic material placed atop for colour change can aid the embedded word or image to appear and increase the human interaction.
- The SMA requires less power for activation (9 V) and the time required for activation is also less.

5 Conclusions

The controller with rapid switching of button patterns in an automobile along with its ability to adapt according to the necessities of the user improves the human-machine interface and also increases the safety of the user in the automobile and the environment in which the automobile is used. This controller is designed such that the activation methods

could be interchanged whenever required but the most suitable activation method is using a SMA spring (NiTi) which requires only 9 V of power to activate. The addition of the protrusion in buttons according to the functions and the buttons and the use of mechanochromic layer on top of the controller along with the haptic feedback already present in the buttons will ensure both the touch and visual feedback and thus improve the human-machine interaction. In the future, the activation of the battery which activates the mechanism will be replaced by sensors and the processors so that the sensors will sense the human interaction and the processors will help in determining the right action required and the corresponding buttons responsible for that actions will become active by providing both visual and touch feedback and also suitable technology could be installed for the provision of auditory feedback, thus enhancing the human-machine interaction.

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